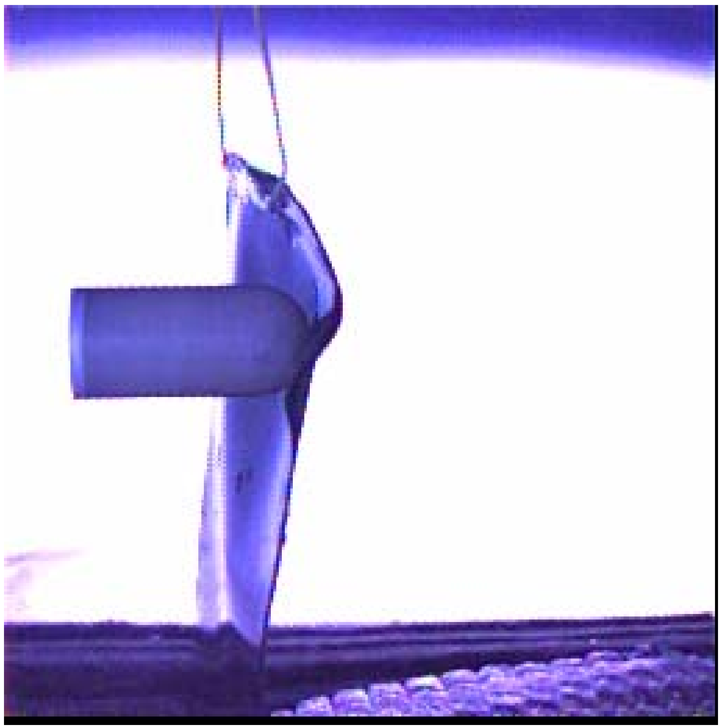
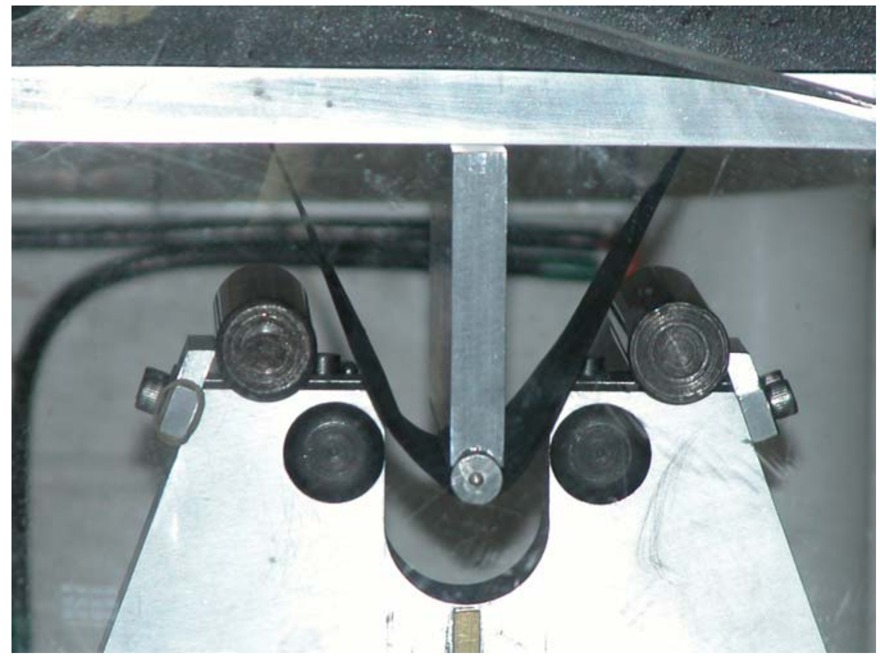
Failure Prediction in Composite Plates with Impact Induced Damage





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Los Alamos
NATIONAL LABORATORY
Dynamics Summer School

A roadmap to the presentation

Motivation/Background

Original plans

Plate description

Testing/Modeling

Results/Conclusions

Damage Prognosis Saves You Money

<u>Benefits</u>

Dynamic Maintenance Schedules
- **Airplanes**
- **Explosive containment vessels**

Life-usage Fees
- **Heavy mining equipment**
- **Rental cars**

We had originally planned to apply a Reliability A

STEP 1: Identify

STEP 2: Identify … e modes

STEP 3: Assume

STEP 4: Create I

Joint Probabili
Density Functi
(JPDF)

afe Region:
$g>0$

Uns
F

imit State:
$g=C-D$

STEP 5: Integrat … robability

Plate Description

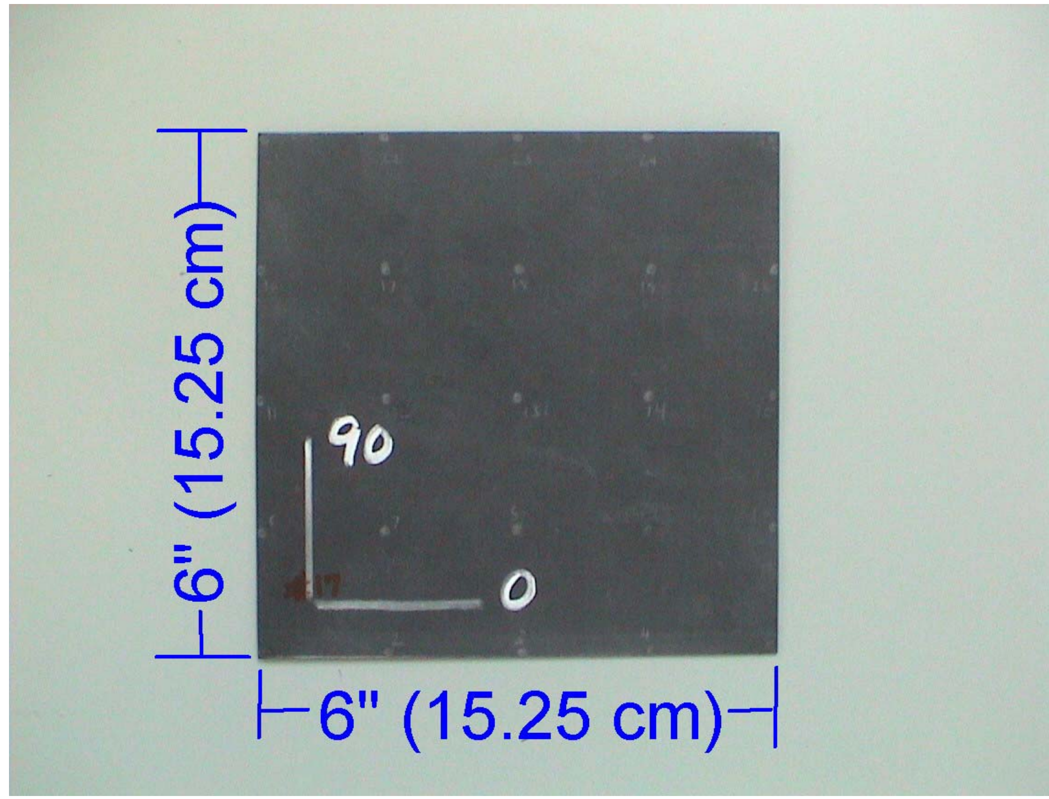
6”x6” (15.25cmx15.25cm)

Eight ply composite
 0-45-90-135

T-700 fibers in a Graphite Epoxy Matrix

Fiber volume fraction 0.6

Cut from 13”x13” plates



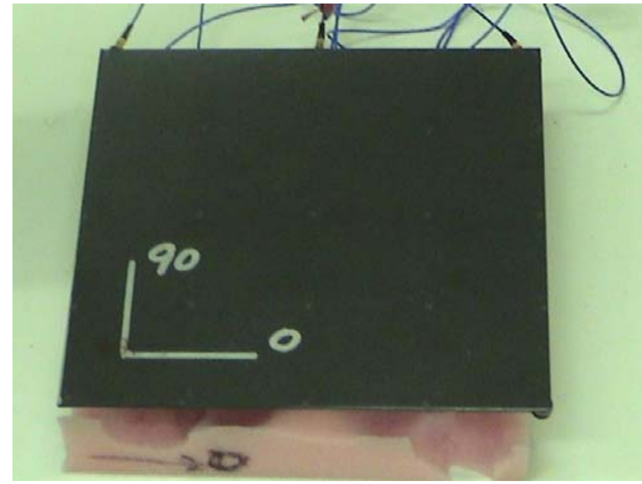
Modal test was done on plates to determine baseline characteristics

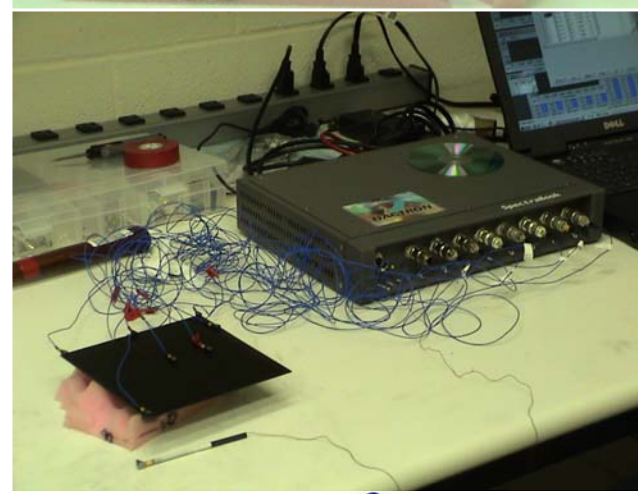
Supported by packing foam

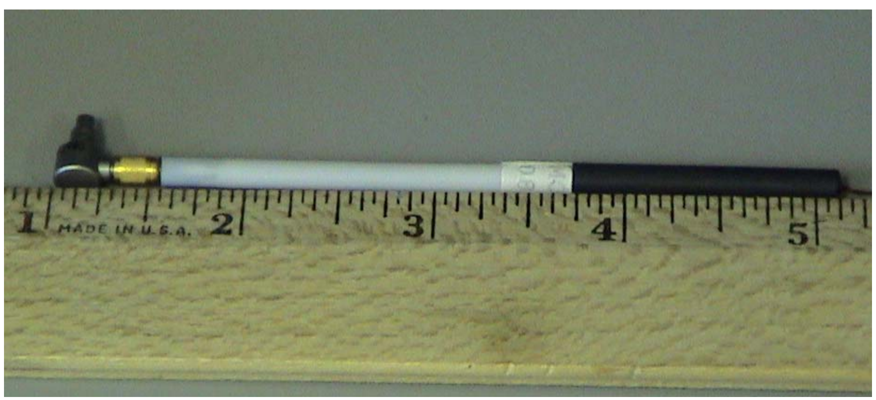
Instrumented with 7 accelerometers

Roved over 25-point grid

10 averages per point





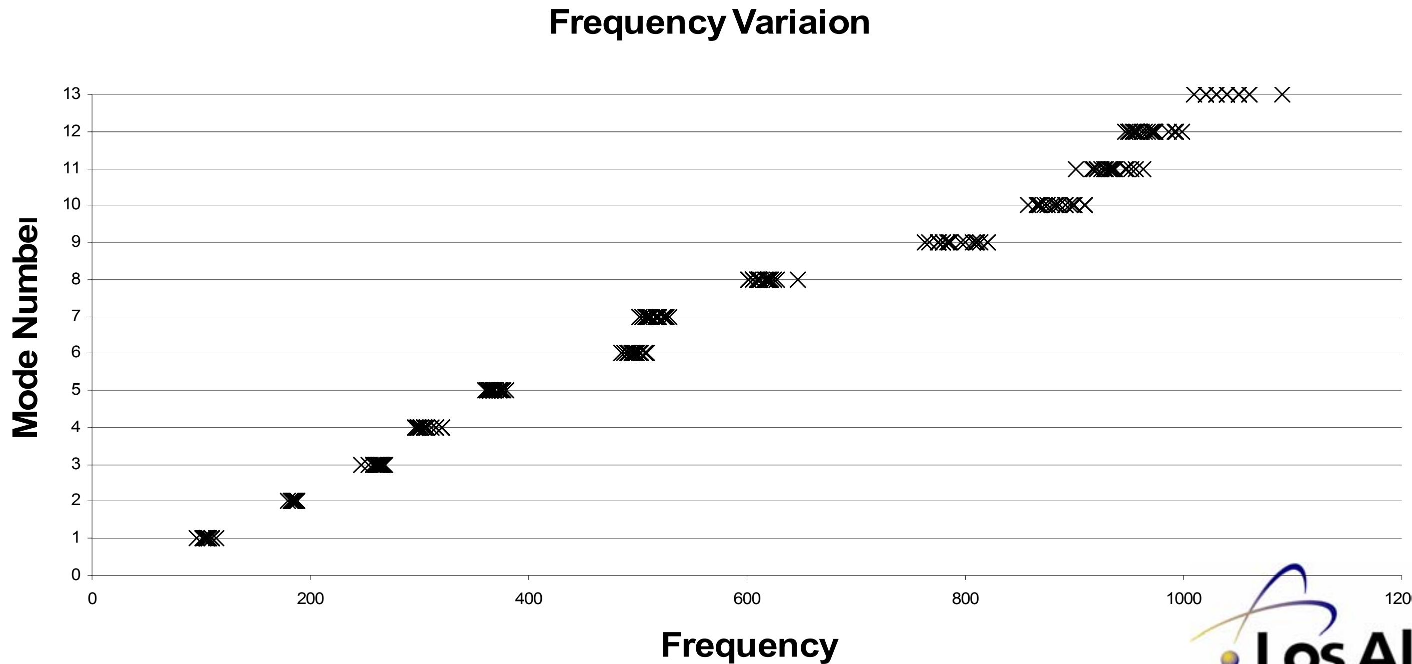


Modal test data was then analyzed to get frequencies, damping, and mode shapes

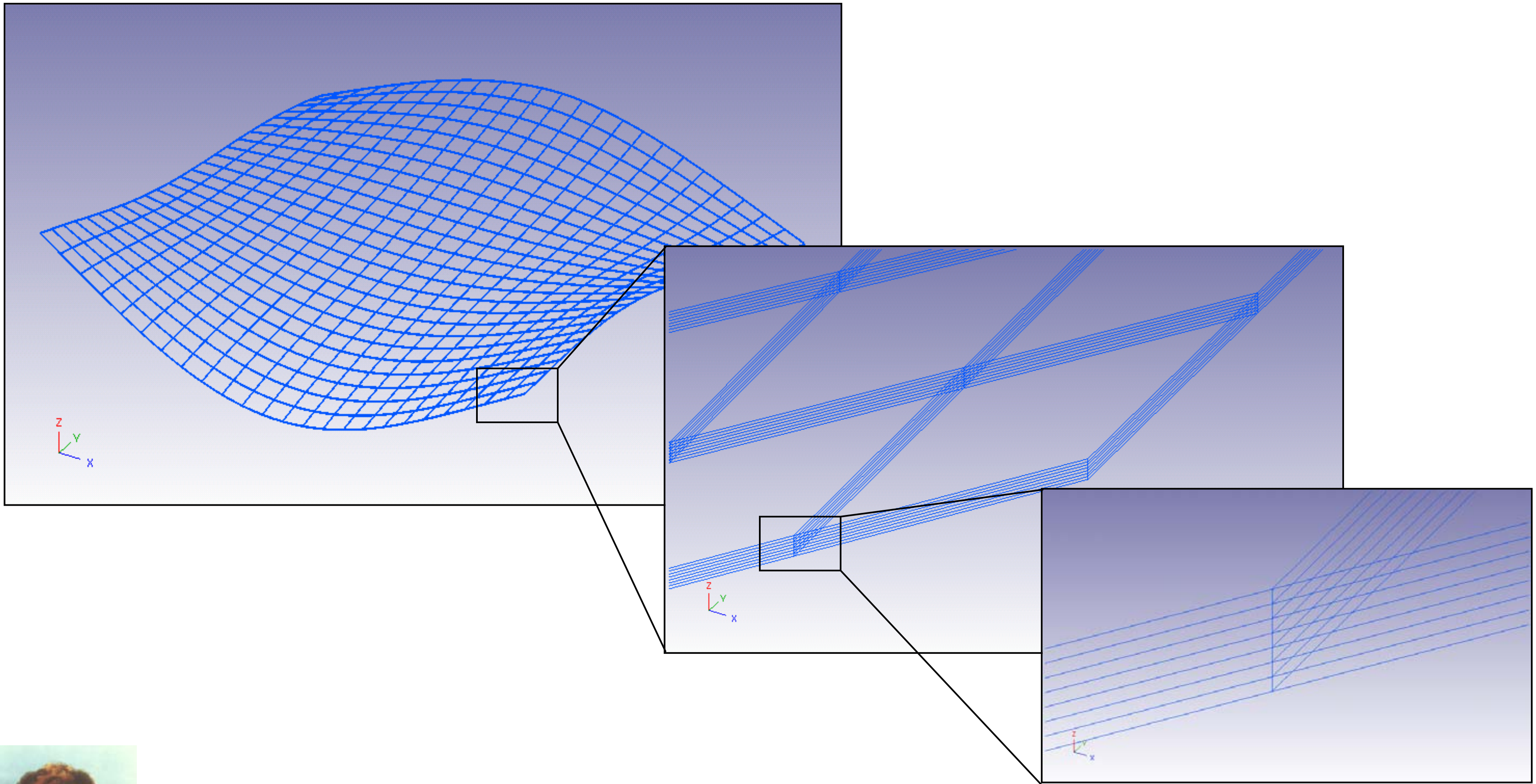
FRFs analyzed in MEScopeVES

Frequencies repeatable within 1-2% for each plate

5% frequency difference between plates



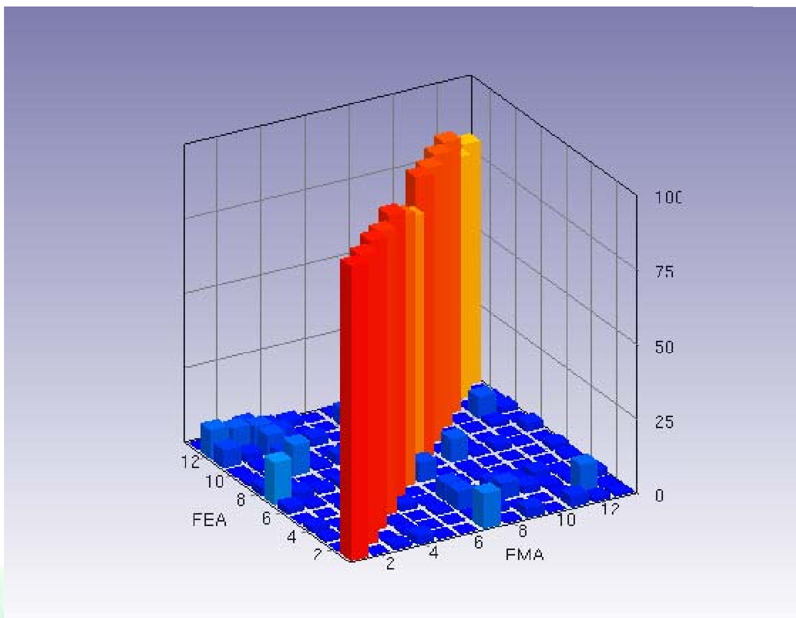
A finite element model was developed to model the plates



A finite element model predicted the behavior of the undamaged plates

Mass loading of accelerometers was significant (1.2% of total mass)

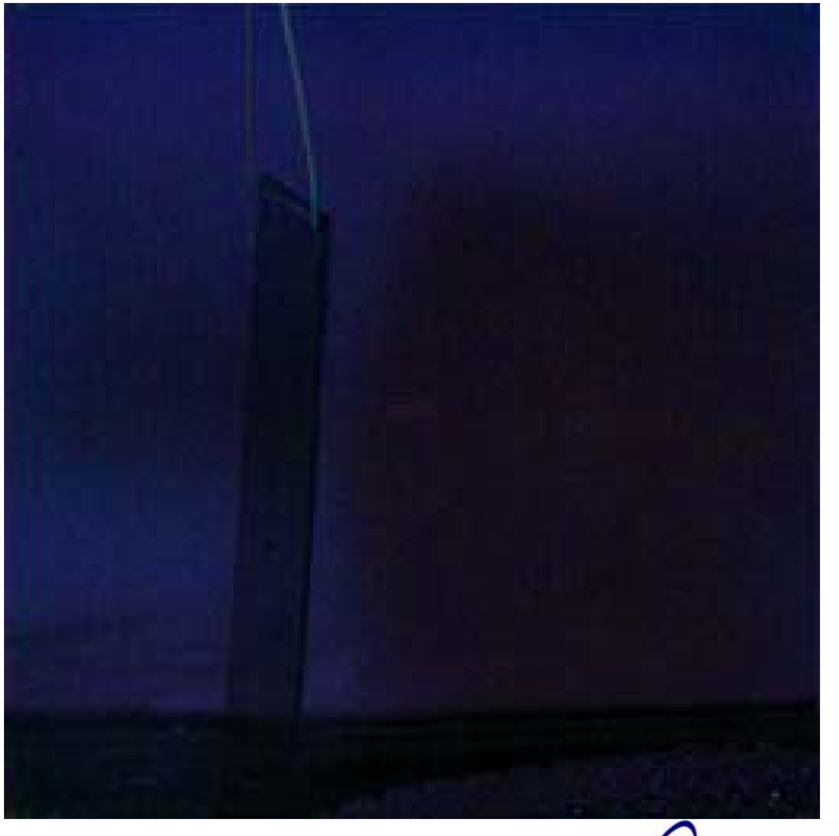
Average MAC 92% lowest 81%



	1	2	3	4	5	6	7	8	9	10	11	12	13
1	99	0	1.3	2.9	0.5	0.1	11.8	0.4	3.3	0	3.7	1.4	1
2	0.1	98	0	0.8	0.3	0.3	0.9	2.4	0.1	0.1	0.9	9.4	0.5
3	0.9	0.7	98	0.7	0.1	1.1	6.3	0.5	5.3	2.7	1	1.1	2.3
4	1.6	0.1	4	96	2	0.5	5.9	0.1	2.8	1.7	2.6	0.6	0.1
5	0.1	0	0.9	0.5	97	0.1	0	0.7	0.9	0.3	0.3	0.1	1.1
6	2.4	0.9	0.1	1.3	4	91	6.6	0	0.4	0.1	0.1	0.1	1.9
7	14.3	2.3	1.4	1.9	0.8	0.2	86	0.3	7.9	0.9	2.1	0.5	0.2
8	2.8	0.9	0	0.4	0.3	0	9.6	95	0	0.1	0.1	0.2	2.7
9	1	0.6	10.4	1.2	3.4	0.3	7.6	0	93	0.4	0.5	1.7	0.2
10	0.3	1	4.7	0.2	0.1	0.1	0.1	0.4	1.7	92	0.2	7.2	2
11	6.1	2.8	7.5	2.7	2.9	0.1	2.2	2.8	5.5	0.2	91	0	1.2
12	9.7	8.3	7.3	4.1	0.4	0.1	5.6	0	1.5	0	5.6	81	0.1
13	0.1	0.3	5	2.7	2.2	0	0.8	0.6	0.8	4.4	4.8	0.7	81

The plates were shot with a nylon projectile to induce damage.

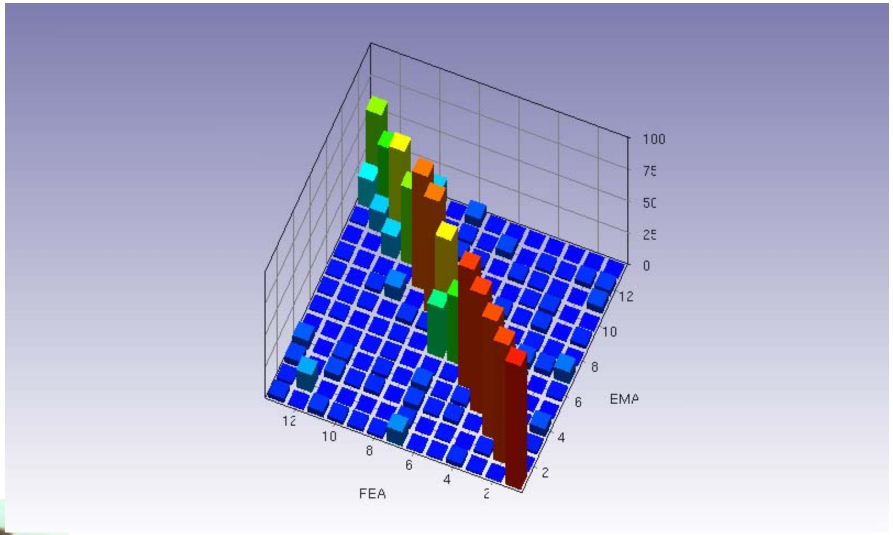
- Hung from 22 gauge wire with 5 min epoxy.
- Projectile Properties
  - 31 grams
  - 0.5 inch diameter
  - hemispherical tip
  - 50 m/s (1/4 speed of .22)
- Shot from a pressurized air gun

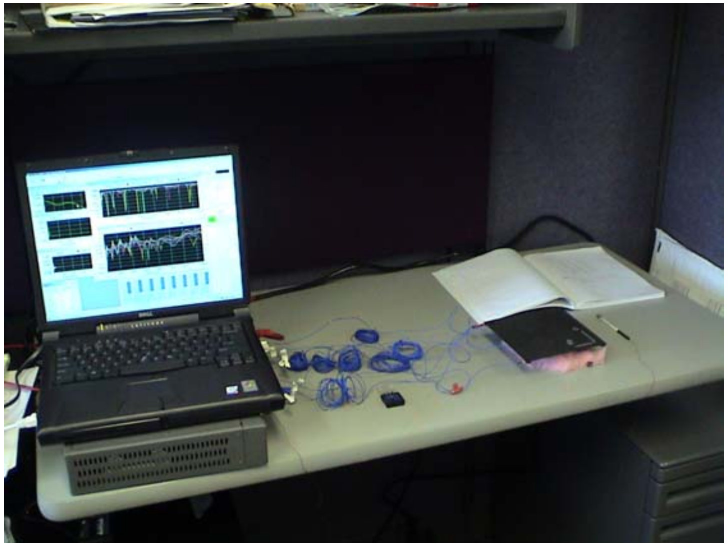


The plates were re-characterized after damage

Exact same testing conditions as before damage.

13 modes found again.



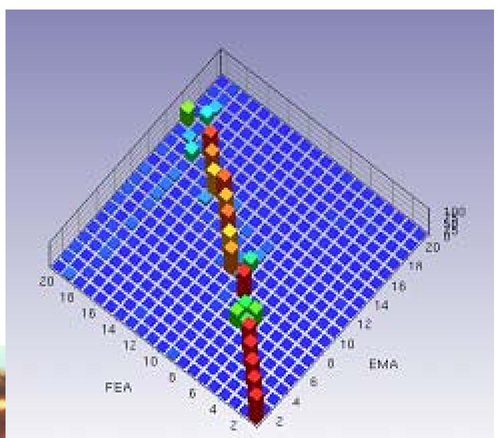


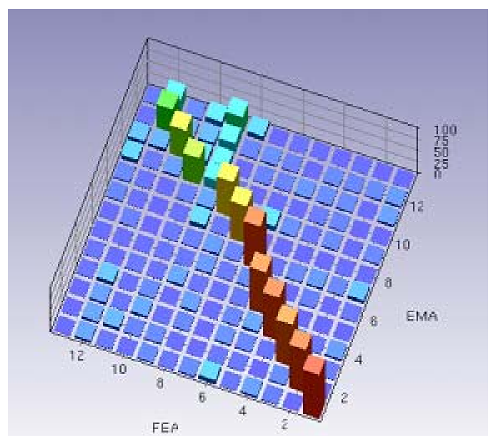
Finite element damage predictions

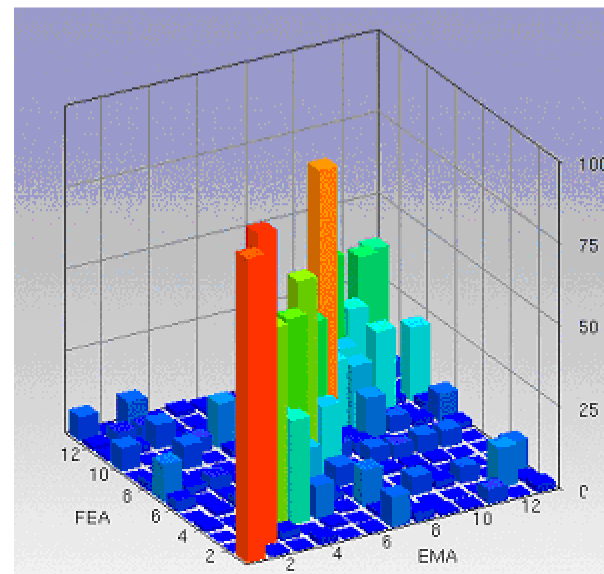
Predicted added mode which occurred at mode 6 in test (3) plates

Didn't model the experimental well at all

Due to matrix cracking (not modeled)



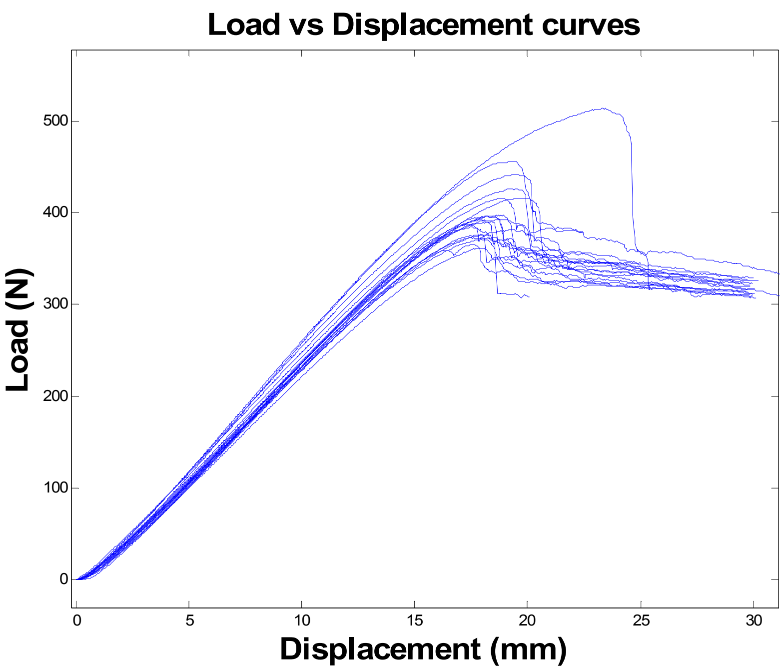


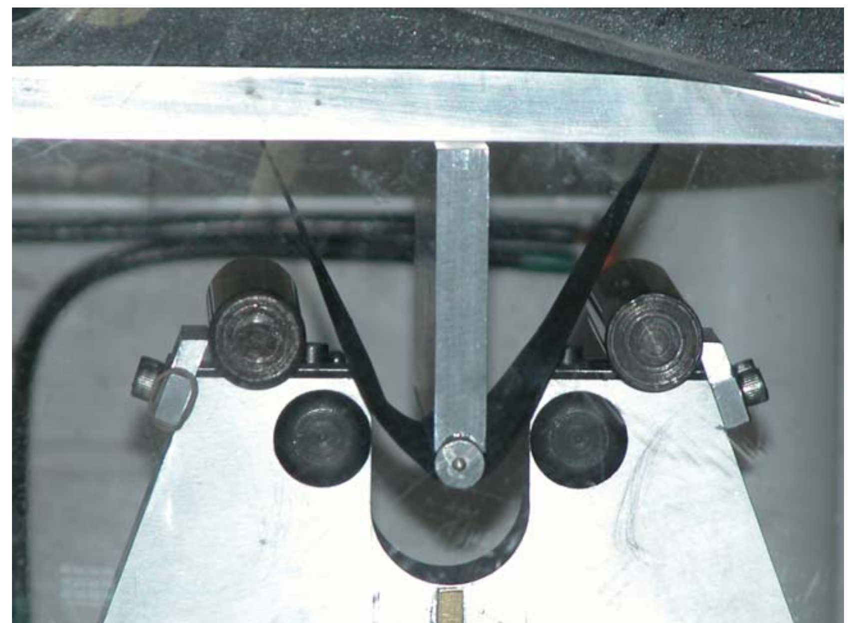


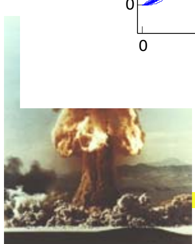
It was attempted to find the ultimate strength of the plates

Plates bent but didn't break.

"ultimate strength" that was gotten was a factor of friction





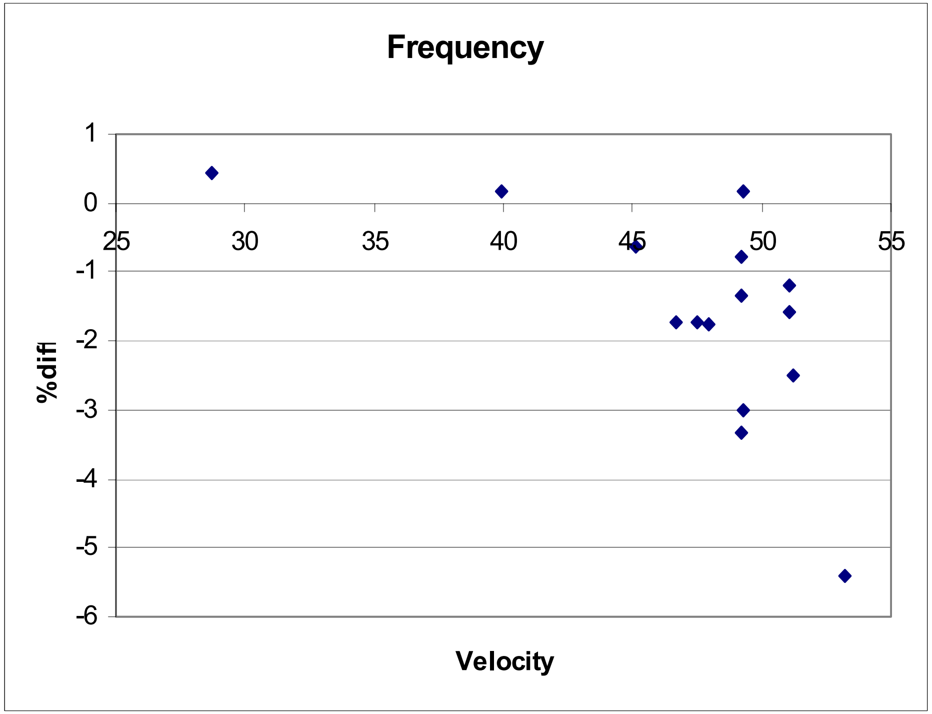


Frequency shifts were negligible

Average Frequency shift for all modes was 1%, which is inside the measured variability

A general trend is seen

Scatter too large + change is too small to pull any real meaning from the data



Local stiffness changes were analyzed for trends

$$\frac{\partial H_{pq}}{\partial k_{mn}} = \left(H_{pm} - H_{pn}\right)\left(H_{qm} - H_{qn}\right)$$

Derived for lumped mass System

Plate is continuous

$$\partial H_{pq} \approx \Delta H_{pq} = \left(H_{pq}\right)_{und} - \left(H_{pq}\right)_{dmg}$$

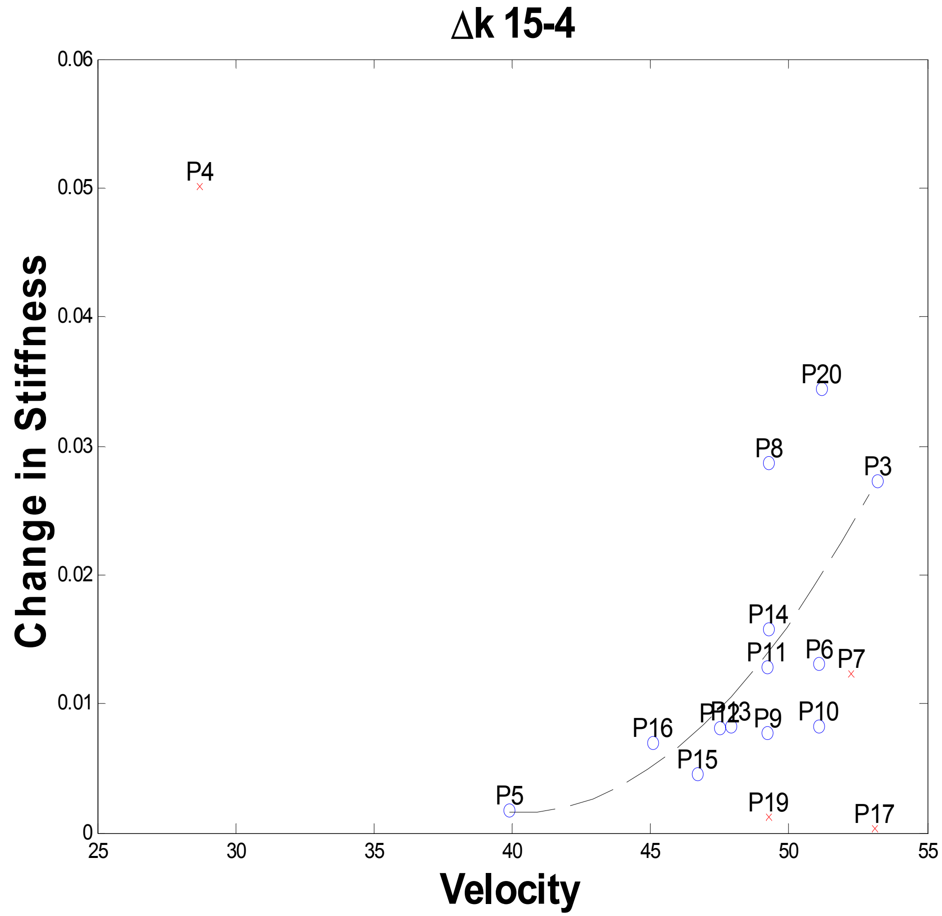
$$\Delta k_{mn} = \frac{\left(H_{pq}\right)_{und} - \left(H_{pq}\right)_{dmg}}{\left[\left(H_{pm}\right)_{und} - \left(H_{pn}\right)_{und}\right]\left[\left(H_{qm}\right)_{und} - \left(H_{qn}\right)_{und}\right]}$$

Change in stiffness gave almost same data as change in frequencies

3 plates excluded because damage was different.

Process of computing a meaningful stiffness change complicated.

Results not always consistent.



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Conclusions that could be pulled from the data

Original goal was unattainable due to variability between plates + plates didn’t break.

Strength we did get was a factor of friction

Some general trends could be seen in data

Frequency shift too small

Some recommendations for future study

Frequency shift might not be best indicator of damage.

Find damage indicator that is sensitive enough to damage

Find better way to test ultimate strength of plates

Try higher velocities to see if trends continue

Testing different geometries (real world)

Test Commercially manufactured plates for unit to unit variability

We would like to thank the following people and companies

People:

Chuck Farrar

Pete Avitabile

Software:

FEMtools

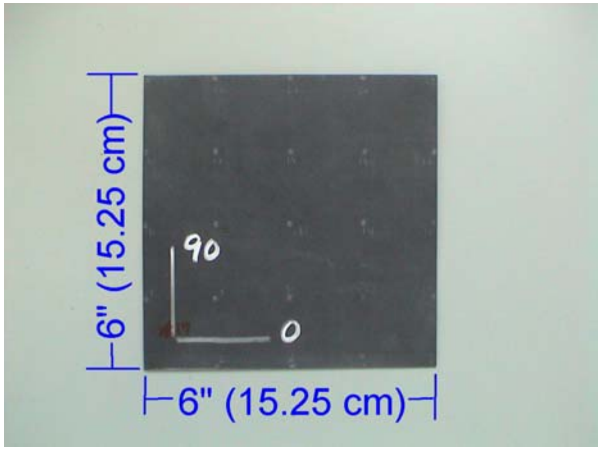
MATLAB

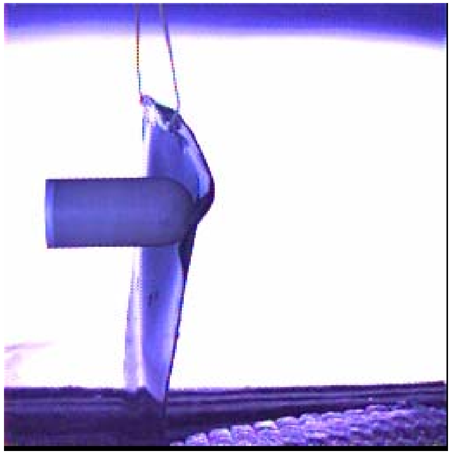
Dactron

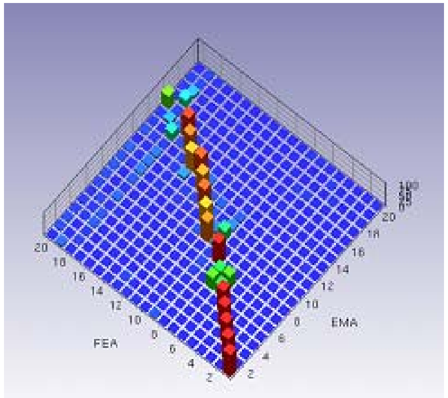
MEScopeVES

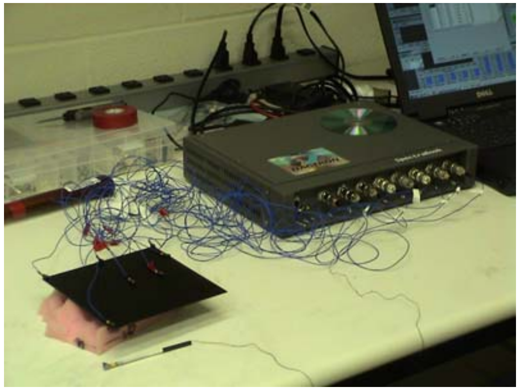
Abaqus

Are there any Questions?









$$\Delta k_{mn} = \frac{(H_{pq})_{und} - (H_{pq})_{dmg}}{\left[(H_{pm})_{und} - (H_{pn})_{und}\right]\left[(H_{qm})_{und} - (H_{qn})_{und}\right]}$$